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Barnacles and mussels as biomonitors of trace elements: a comparative study

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ABSTRACT: Concentrations of 5 trace elements (cadmium, chromium, copper, lead, zinc) in 3 species of barnacle and the mussel *Perna viridis* were determined for up to 18 sites in Hong Kong coastal waters. Although each species accumulated differing absolute amounts of metals, qualitative agreement between contamination profiles exhibited by the 4 species for all elements other than cadmium was excellent. This was the case even for zinc, which is partially regulated by *P. viridis*. The relative bioavailabilities of metals other than cadmium to each of the 4 species at the sites studied are thus similar for the barnacle species and the mussel, and a consistent pattern of environmental contamination emerges from these data. By contrast, the bioavailability of cadmium appears to differ between each species; this may be at least partly due to the lack of a marked gradient in cadmium contamination of Hong Kong waters, as shown by previous studies and confirmed here. The differences between the species in trace metal accumulation are discussed, particularly as they relate to the use of barnacles and mussels as biomonitors of aquatic contamination. It is suggested that these species should be further employed in subtropical and tropical nations to establish present levels of contamination and monitor future trends.

INTRODUCTION

The use of aquatic organisms to monitor trace metal abundance and bioavailability in coastal waters is well established, especially in temperate regions (Phillips 1977, 1980, Goldberg et al. 1978, Bryan et al. 1980, 1985). Bivalve molluscs are generally thought to be among the best species for such studies (Phillips 1980), although barnacles have also been used successfully (Rainbow 1987).

One of the advantages of employing biomonitors to assess the abundance of trace metals in aquatic ecosystems is that the element levels found in their tissues are by definition a function of the amounts of bioavailable metals present in the environment. No such measure of bioavailability may be provided by the analysis of contaminants in water or sediments, as too little is known of the relative or absolute availabilities of metals in different forms to biota (Phillips 1980). However, the concept of bioavailability is itself complex, as different organisms may take up metals more or less efficiently from solution, suspension, or food. Studies comparing trace metal profiles from several biomonitors taken at the same locations permit an assessment of the relative bioavailabilities of metals to different species. Unfortunately, such investigations are rare even in temperate regions, and almost nonexistent in warmer waters.

Hong Kong coastal waters are ideal to test the capacity of different organisms to monitor trace metal abundance, as a well defined gradient of contamination exists. Studies of sediments, oysters and mussels have clearly shown trace element enrichment in the heavily urbanized Victoria Harbour area (receiving sewage wastes from 3.7 million inhabitants, and associated industrial effluents), concentrations generally decreasing with distance away from the Harbour (Phillips 1979a, 1985, Phillips & Yim 1981). The present investigation contrasts contamination profiles found in 4 biomonitor species in these waters, for 5 trace metals (cadmium, chromium, copper, lead, zinc). The species employed were the green-lipped mussel *Perna viridis* and the barnacles *Capitulum mitella*, *Tetraclita squamosa*, and *Balanus amphitrite amphitrite*.

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MATERIALS AND METHODS

Mussels and barnacles were sampled from 8 to 16 April, 1986. Sampling locations were based on a previous survey of mussels (Phillips 1985), with a few minor changes or additions to compensate for the differing distributions of the species studied. Mussels *Perna viridis* (Linnaeus) were taken from 16 locations (Table 1, Fig. 1). Twenty individuals of shell length 50 to 70 mm were collected from similar water depths at each site. The 3 barnacle species – *Capitulum mitella* (Linnaeus), *Tetraclita squamosa* Bruguière (not distinguished into subspecies *T. squamosa squamosa* Bruguière and *T. squamosa japonica* Pilsbry), and *Balanus amphitrite amphitrite* Darwin – were collected at all study sites where they were present (Table 1). As *C. mitella* was found at only 4 of the 16 sites where *P. viridis* was taken, 2 additional collection locations for this barnacle were added (Sites 17 and 18 in Fig. 1 and Table 1). Each barnacle species occupied a characteristic zone in the eulittoral or sublittoral, in addition to possessing distinct habitat preferences, especially with respect to wave action (Wu 1973). The effects of size of individuals on trace metal levels in barnacles could not be accounted for by sampling a restricted size range (as for mussels), as many populations consisted predominantly of individuals of a particular size and this differed between locations. The largest individuals present at each site were taken, and statistical treatment of data generated from these was employed (see below) to account for any size effects. For *C. mitella* and *T. squamosa*, at least 10 individuals were analyzed from each site. The smaller size of *B. amphitrite amphitrite* necessitated pooling of 15 bodies to provide each of 10 replicates at each site.

Table 1. Barnacle species (*Balanus amphitrite amphitrite*, *Capitulum mitella* and *Tetraclita squamosa*) sampled at each of the 18 locations shown in Fig. 1. Locations 4 to 10 and 17 are in Victoria Harbour, 11 and 12 in Junk Bay, and 13 to 16 in Tolo Harbour and Channel. *Perna viridis* was sampled at Locations 1 to 16

Code	Location	Barnacle species collected
1	Tung Chung	*T squamosa, B. amphitrite amphitrite*
2	Reef Island	*C. mitella; T. squamosa*
3	Chai Wan Kok	*B. amphitrite amphitrite*
4	Kennedy Town	None
5	Queens Pier	*C. mitella; T squamosa*
6	Kowloon Pier	*T squamosa*
7	Hung Hom	*C. mitella; T squamosa*
8	Causeway Bay	*C. mitella; T. squamosa*
9	North Point	*T. squamosa; B. amphitrite amphitrite*
10	Kwun Tong	*B. amphitrite amphitrite*
11	Rennies Mill	*B. amphitrite amphitrite*
12	Hang Hau	*B. amphitrite amphitrite*
13	Sha Tin	*B. amphitrite amphitrite*
14	Tai Po Kau	*B. amphitrite amphitrite*
15	Wu Kwai Sha	*B. amphitrite amphitrite*
16	Lai Chi Chong	*B. amphitrite amphitrite*
17	Stonecutters Island	*C. mitella*
18	Cape D'Aguilar	*C. mitella*

All species were kept cool during transport to the laboratory. No depuration period was employed, as this may lead to contamination of samples. In any event, depuration has little effect on trace metal levels in the species studied (NAS 1980, Latouche & Mix 1982, Phillips 1985, Rainbow unpubl.).

Mussel samples were stored frozen at − 20 °C until required for analysis. Upon thawing, the whole soft parts were removed using stainless steel instruments

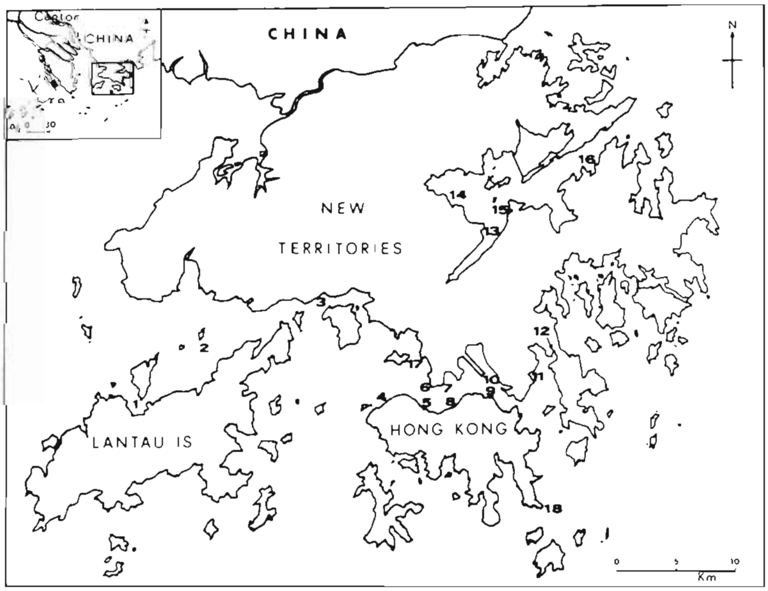

Fig. 1. Hong Kong coastal waters, showing 18 locations at which samples of barnacles (*Capitulum mitella*, *Tetraclita squamosa*, *Balanus amphitrite amphitrite*) and/or mussels (*Perna viridis*) were taken. Locations 4 to 10 and 17 are in Victoria Harbour; 11 and 12, in Junk Bay; and 13 to 16, in Tolo Harbour and Channel. Inset: Hong Kong in relation to southern China

(byssus was discarded). Mussels were analyzed in 5 replicates of 4 individuals for each site, and were homogenized using a Brinkman PT 10-35 Polytron Kinematica ultrasonic blender (confirmed to be non-contaminating in previous studies). Aliquots of 10 g wet weight were digested with 20 ml concentrated HNO_3 at 120 °C and made up to 100 ml with distilled deionized water for analysis. Separate aliquots were dried at 100 °C to constant weight to define wet weight:dry weight ratios. Copper and zinc were analyzed by flame atomic absorption spectrophotometry (AAS) using a Hitachi 180-80 Zeeman spectrophotometer. The other elements were quantified by graphite furnace AAS, on either a Perkin-Elmer Zeeman/3030 instrument (chromium, lead) or a Hitachi 180-80 Polarized Zeeman instrument (cadmium). Barnacle samples, consisting of individual or pooled bodies, were dried in acid-washed plastic vials to constant weight, prior to digestion at 100 °C in concentrated HNO_3. Digests were typically made up to 5 ml with double-distilled water. Analysis was by flame AAS on either a Varian AA 375 or an IL 157 spectrophotometer. Throughout all analyses, quality control was provided by concurrent analytical checks on certified reference materials. These included NIES material no. 6 (mussel) for work on *Perna viridis,* and NRC Canada TORT-1 (lobster hepatopancreas) for barnacle analyses. Agreement with certified values was good throughout.

Statistical data treatment employed 2 parametric techniques. Pooling of tissue from mussels of similar sizes from each site overcame possible effects of mussel size on metal concentrations. It is possible, therefore, to compare mean metal concentrations in mussel soft tissue from each site by analysis of variance (ANOVA). In the case of each metal, sample variances increased with means and it was necessary to use logarithmically-transformed values to ensure normal distributions of data. For barnacles, it was first necessary to check whether any residual effects of body size on metal concentrations remained after choice of the largest available specimens at each site and after any pooling of bodies (for *Balanus amphitrite amphitrite*). Data for each metal at each site were checked for significant correlations and regressions between metal concentration (y) in $\mu g\ g^{-1}$ dry weight and body dry weight (x) in g (or mean body dry weight in the case of pooled bodies). In many cases, significant regressions ($p < 0.05$) were found, the data often being a better fit to a straight line after logarithmic transformation [log metal concentration (y) against log dry weight (x)]. Transforming the data to log values also has the advantage of further normalizing the data, a prerequisite for the use of parametric statistics.

To allow for size effects, analysis of covariance (ANCOVA) was employed. ANCOVA tests for significant differences in values of y (log metal concentration) between regression lines fitted to each set of data, having allowed for differences in values of x (log dry weight). In effect, ANCOVA compares predicted metal concentrations of bodies of a particular barnacle species from several sites at a standardized body dry weight. The weights chosen represented approximate medians of the ranges of body weights for each species of barnacle; these were 0.05 g for *Capitulum mitella,* 0.02 g for *Tetraclita squamosa,* and 0.004 g for *Balanus amphitrite amphitrite.*

ANOVA and ANCOVA treatments thus ranked analytical data for each element and species in decreasing order of contamination of samples. Comparisons between the ranking of sites for each metal in mussels and barnacles employed Spearman's rank correlation.

RESULTS

Results for each metal are presented graphically and in Tables 2 to 6. Data for barnacles are shown as estimated concentrations in barnacle bodies of standardized weight, generated from ANCOVA analyses, with 95 % confidence limits. Concentrations of metals are assigned letters (A, B, C, etc.) in tables from ANCOVA (barnacle) or ANOVA (mussel) data; these differ where significantly different element concentrations were present in different samples. Sites are ranked in approximate order of decreasing concentration of trace elements. In Figs. 2 to 6, such ranking of metal levels is shown by the use of circles of differing diameters.

Cadmium concentrations in mussels and barnacles are shown in Table 2 and Fig. 2. Each species exhibited somewhat elevated levels of cadmium at Reef Island, but differences in contamination profiles existed for other sites between species. Barnacle data suggest relatively high cadmium bioavailability at North Point and in Victoria Harbour, whereas *Perna viridis* attained highest cadmium levels at Rennies Mill. Comparison of rank orders of sites from barnacle and mussel data using Spearman's rank correlation tests revealed no significant correlation ($r_s = 0.514$, $n = 15$, NS), even if data from Rennies Mill were excluded ($r_s = 0.495$, $n = 14$, NS). This suggests that barnacles and *P. viridis* differ with respect to their net uptake of cadmium, i.e. that cadmium bioavailability to barnacles is distinct from that to green-lipped mussels. It is also notable that little variation in cadmium concentrations between sites was evident, confirming earlier conclusions (Phillips 1979a, 1985) that no major cadmium source or contamination gradient exists in Hong Kong waters.

Concentrations of chromium in the species analyzed are presented in Table 3 and Fig. 3. No data are

Table 2. Concentrations of cadmium ($\mu g\ g^{-1}$ dry wt) and respective confidence limits (CL) in barnacles and mussels from Hong Kong waters, ranked in approximate order of decreasing contamination of samples. Letters in ANCOVA and ANOVA columns denote presence or absence or significant differences between samples

Location (code)	*Capitulum mitella*			*Tetraclita squamosa*			*Balanus amphitrite amphitrite*			*Perna viridis*		
	(Cd)	CL	ANCOVA	(Cd)	CL	ANCOVA	(Cd)	CL	ANCOVA	(Cd)	CL	ANOVA
Reef Island (2)	4.4	5.7 3.4	B	7.7	12.6 4.7	A				1.06	1.31 0.81	B
North Point (9)				6.1	7.9 4.7	A	10.1	11.5 8.9	A	0.22	0.36 0.08	E, F
Causeway Bay (8)	5.2	6.9 4.0	A	5.4	20.0 1.4	A				0.36	0.53 0.19	D
Chai Wan Kok (3)							7.3	8.9 5.9	B	0.51	0.93 0.09	C
Kwun Tong (10)							6.9	8.8 5.5	B	0.52	0.69 0.35	C
Hung Hom (7)	10.0	15.9 6.2	A	2.8	5.2 1.5	B				0.34	0.45 0.23	D
Stonecutters (17)	7.2	10.2 5.0	A									
Rennies Mill (11)							5.8	7.3 4.7	C	1.48	2.67 0.29	A
Tung Chung (1)				4.2	6.5 2.7	B	2.7	7×10^7 0	C	0.52	0.63 0.41	C
Kennedy Town (4)										0.44	0.66 0.22	C
Hang Hau (12)							4.2	5.1 3.4	C	0.39	0.58 0.20	C
Kowloon Pier (6)				3.8	4.9 3.0	B				0.27	0.41 0.13	E
Cape D'Aguilar (18)	5.2	5.7 4.7	B									
Queens Pier (5)	2.9	4.4 1.9	B	3.6	4.4 2.9	B				0.34	0.51 0.17	D
Wu Kwai Sha (15)							4.4	5.0 3.9	C	0.20	0.26 0.14	F
Lai Chi Chong (16)							5.5	22.6 1.4	C	0.19	0.30 0.08	F
Tai Po Kau (14)							4.1	7.4 2.2	C	0.15	0.29 0.01	F
Sha Tin (13)							2.1	2.5 1.7	D	0.20	0.23 0.17	F

available for *Tetraclita squamosa*, as chromium levels were too low to permit reliable quantification in this species. Data for the other 2 barnacle species and for mussels exhibited a high correlation between the ranking of sites ($r_s = 0.891$, $n = 15$, $p < 0.001$), indicating excellent agreement between chromium contamination profiles. This implies that the bioavailability of chromium to each species analyzed is similar. Concentrations of chromium were highest in all species at Chai Wan Kok, and elevated levels were also found at Kwun Tong and in the remainder of Victoria Harbour.

Data for copper are shown in Table 4 and Fig. 4. As seen for chromium, barnacle and mussel data present a consistent pattern of contamination. Samples from Chai Wan Kok and Kwun Tong exhibited notably elevated levels of copper, and the Victoria Harbour area was again generally contaminated. Comparison of site ranking shows a highly significant correlation between barnacles and mussels ($r_s = 0.902$, $n = 15$, $p < 0.001$).

Concentrations of lead in the species analyzed are presented in Table 5 and Fig. 5. The contamination profile for lead was distinct from that for other elements, highest concentrations being found in sites in Junk Bay (Hang Hau and Rennies Mill), with mussels from Chai Wan Kok and Kennedy Town also exhibiting heavy contamination. Lead levels in samples from Vic-

Table 3. Concentrations of chromium (μg g^{-1} dry wt) and respective confidence limits (CL) in barnacles and mussels from Hong Kong waters, ranked in approximate order of decreasing contamination of samples. Letters in ANCOVA and ANOVA columns denote presence or absence of significant differences between samples

Location (code)	*Capitulum mitella*			*Balanus amphitrite amphitrite*			*Perna viridis*		
	(Cr)	CL	ANCOVA	(Cr)	CL	ANCOVA	(Cr)	CL	ANOVA
Chai Wan Kok (3)				28.0	35.0 22.4	A	37.6	44.8 30.4	A
Kwun Tong (10)				12.9	14.8 11.2	B	16.9	25.9 7.9	B
Hung Hom (7)	48.5	355 6.6	A				7.6	9.1 6.1	C
Stonecutters (17)	7.8	16.4 5.7	A						
Queens Pier (5)	6.3	9.2 4.3	B				12.5	35.5 0	B
Kennedy Town (4)							9.5	14.5 4.5	B
Causeway Bay (8)	7.4	9.7 5.6	B				6.6	12.5 0.7	C
Kowloon Pier (6)							5.2	8.3 2.1	D
Reef Island (2)	3.3	5.2 2.1	C				4.7	9.1 0.3	D
North Point (9)				5.0	6.1 4.0	C	4.5	7.9 1.1	D
Rennies Mill (11)				3.7	5.8 2.4	C	4.1	5.5 2.7	D
Sha Tin (13)				3.4	4.1 2.8	D	3.7	5.7 1.7	D
Tung Chung (1)							3.0	8.0 0	D
Hang Hau (12)				3.0	4.0 2.3	D	3.0	6.1 0	D
Wu Kwai Sha (15)				1.8	2.3 1.4	E	5.1	12.1 0	D
Tai Po Kau (14)				0.22	6×10^8 0	F	3.0	7.6 0	D
Lai Chi Chong (16)				0.55	1.7 0.18	F	1.2	2.1 0.3	E
Cape D'Aguilar (18)	0.98	6.6 0.15	D						

toria Harbour were generally greater than those from north-eastern waters. Comparison of the ranking of sites in barnacle and mussel data again reveals a highly significant correlation ($r_s = 0.890$, $n = 15$, $p < 0.001$).

Data for zinc are shown in Table 6 and Fig. 6. All 3 barnacle species exhibited a wide range in accumulated zinc concentrations, with considerable site-to-site variation which was generally consistent between species. This implies the existence of large variability in bioavailable zinc concentrations between sites, as suggested by previous studies of oysters and sediments from these waters (Phillips 1979a, Phillips & Yim 1981). By contrast, zinc concentrations in *Perna viridis* varied over a much restricted range, with means for different sites ranging only from 55 to 153 μg g^{-1} dry weight. These data agree well with the previous results of Phillips (1985) for *P. viridis* and suggest that this mussel partially regulates its tissue zinc concentrations. Notwithstanding such differences in absolute variability between zinc levels in the 4 species analyzed, the rank orders of sites from barnacle and mussel data exhibit a highly significant correlation ($r_s = 0.856$, $n = 15$, $p < 0.001$). Sites in Victoria Harbour and Junk Bay are of greatest zinc bioavailability, as noted in previous studies of different biomonitor species and sediments (Phillips 1979a, Phillips & Yim 1981).

DISCUSSION AND CONCLUSIONS

The fact that the analysis of biomonitors for contaminants provides a direct measure of pollutant bioavailability in aquatic ecosystems (Phillips 1980) has been a major driving force in the trend towards the use

Table 4. Concentrations of copper (μg g^{-1} dry wt) and respective confidence limits (CL) in barnacles and mussels from Hong Kong waters, ranked in approximate order of decreasing contamination of samples. Letters in ANCOVA and ANOVA columns denote presence or absence of significant differences between samples

Location (code)	*Capitulum mitella*			*Tetraclita squamosa*			*Balanus amphitrite amphitrite*			*Perna viridis*		
	(Cu)	CL	ANCOVA	(Cu)	CL	ANCOVA	(Cu)	CL	ANCOVA	(Cu)	CL	ANOVA
Chai Wan Kok (3)							3472	3950 3052	A	219	338 100	A
Kwun Tong (10)							2574	3414 1940	B	149	209 88.6	B
North Point (9)				203	243 170	A	1010	1387 869	C	26.7	44.9 8.5	F
Hung Hom (7)	545	1290 375	A	94.9	129 69.9	B				60.1	81.6 38.6	C
Kowloon Pier (6)				80.7	92.0 70.7	B				24.7	34.5 14.9	F
Stonecutters (17)	537	1170 247	A									
Queens Pier (5)	154	435 54.4	B	80.1	91.3 70.3	B				24.0	30.2 17.8	F
Causeway Bay (8)	132	232 74.6	B	69.2	98.2 48.7	B				38.5	52.2 24.8	D
Kennedy Town (4)										29.1	38.6 19.6	E
Hang Hau (12)							486	639 373	D	20.8	36.5 5.1	F
Reef Island (2)	36.5	53.4 25.0	C	30.9	41.3 23.2	C				20.8	34.6 7.0	F
Rennies Mill (11)							304	368 251	E	13.5	18.9 8.1	G
Tung Chung (1)				14.9	24.3 9.1	D	295	13670 6.4	E	9.5	13.3 5.7	H
Wu Kwai Sha (15)							213	244 187	F	15.9	24.8 7.0	G
Tai Po Kau (14)							142	235 86.2	G	11.2	19.0 3.4	G
Sha Tin (13)							116	136 98.5	H	12.6	15.3 9.9	G
Lai Chi Chong (16)							59.3	195 18.0	H	10.9	14.8 7.0	H
Cape D'Aguilar (18)	29.2	35.6 24.1	D									

of organisms to monitor water quality. However, it is clear that bioavailability is not of an absolute nature, as some organisms are able to accumulate contaminants that other species do not take up. This is likely to depend largely upon general feeding habits and specific dietary preferences. Thus, for example, deposit feeders may respond to metals in different portions or phases of the biosphere to organisms feeding on phytoplankton. Similarly, differences between contaminant levels in various species at the base of the food chain may translate to divergent rates of accumulation of such toxicants by higher organisms, if specific dietary preferences exist.

As a result of such differences, it should not be surprising that contamination profiles produced by the study of several species do not always agree qualitatively or quantitatively. Bryan & Hummerstone (1977) found that the pattern of silver accumulation in several organisms from the Looe Estuary, UK, varied between species. Macroalgae and the herbivorous limpet *Patella vulgata* exhibited little variation in silver concentrations with distance upriver, while filter-feeders such as the cockle *Cerastoderma edule* exhibited elevated silver levels in upriver locations. Such differences were also reported for contaminant profiles in macroalgae (*Fucus vesiculosus*) and mussels (*Mytilus edulis*) from the Sound between Denmark and Sweden by Phillips (1979b). In these cases, divergent contamination profiles were found in the species studied because the ratio of toxicant levels in solution to those in suspension or food varied non-systematically between the study sites. The importance of dietary habits was emphasized by

Table 5. Concentrations of lead (μg g^{-1} dry wt) and respective confidence limits (CL) in barnacles and mussels from Hong Kong waters, ranked in approximate order of decreasing contamination of samples. Letters in ANCOVA and ANOVA columns denote presence or absence of significant differences between samples

Location (code)	*Capitulum mitella*			*Tetraclita squamosa*			*Balanus amphitrite amphitrite*			*Perna viridis*		
	(Pb)	CL	ANCOVA	(Pb)	CL	ANCOVA	(Pb)	CL	ANCOVA	(Pb)	CL	ANOVA
Hang Hau (12)							39.2	68.6 22.4	A	40.8	50.0 31.6	A
Rennies Mill (11)							36.5	45.2 29.4	A	45.6	79.7 11.5	A
Chai Wan Kok (3)							12.7	16.0 10.0	B	47.8	109 0	A
Kennedy Town (4)										37.5	62.2 12.8	A
Hung Hom (7)	8.5	14.1 5.1	A	4.4	6.9 2.7	A				14.9	19.9 9.9	B
Stonecutters (17)	6.6	13.5 3.2	A									
Kowloon Pier (6)				4.3	31.2 0.6	A				11.7	22.5 0.9	B
Causeway Bay (8)	4.3	6.8 2.7	A							10.2	18.8 1.6	B
Queens Pier (5)	3.1	5.9 1.6	B	3.9	5.7 2.7	A				12.7	23.2 2.2	B
North Point (9)				3.9	5.1 3.0	A	8.5	13.8 5.2	C	10.5	18.6 2.4	B
Reef Island (2)	4.1	13.1 1.3	B	4.4	10.6 1.8	A				5.3	8.4 2.2	C
Cape D'Aguilar (18)	3.0	3.4 2.6	B									
Tung Chung (1)				2.2	5.1 0.9	B	12.7	3×10^{11} 0	B	4.1	6.6 1.6	C
Kwun Tong (10)							4.1	8.1 2.0	C	11.1	16.9 5.3	B
Wu Kwai Sha (15)							9.2	12.1 7.0	C	5.7	8.5 2.9	C
Tai Po Kau (14)							3.8	8.3 1.7	C	3.7	10.4 0	C
Sha Tin (13)							1.7	2.4 1.3	D	2.3	2.9 1.7	D
Lai Chi Chong (16)							2.8	19.9 0.4	D	1.4	2.2 0.6	E

the results of Ireland & Wootton (1977) in comparisons of contaminant profiles in the gastropods *Thais* (now *Nucella*) *lapillus* and *Littorina littorea* from 9 sites around the coast of Wales, UK. The carnivore *T. lapillus* exhibited distinct contaminant profiles from those of the herbivore *Littorina littorea.* More recent data of several authors (e.g. see Bryan & Gibbs 1983, Bryan et al. 1985, Langston 1986) have confirmed such differences and expanded the current understanding of the use of biomonitors in defining time-averaged bioavailable contaminant levels in coastal waters.

The present study extends these observations to comparisons of barnacles and the mussel *Perna viridis,* employing an area with a well-defined pollution gradient. Although all 4 species studied are filter-feeders, the precise dietary preferences differ between the species. In particular, the barnacles *Capitulum mitella* and *Tetraclita squamosa* prefer larger zooplankton food, while *Balanus amphitrite amphitrite* is more microphagous in nature (Anderson 1981), capable of feeding on phytoplankton and detritus of a size range similar to that taken by *P. viridis.* The bioavailability of trace metals to each species may therefore differ, particularly where pollution gradients are subtle rather than extreme.

In general, the agreement between contamination profiles derived from data on mussels and barnacles was found to be good. Thus, for chromium, copper, lead and zinc, a high degree of correlation of site ranking (from most contaminated to least) was found, despite the fact that *Perna viridis* partially regulates its soft tissue levels of zinc. This partial regulation was first

Table 6. Concentrations of zinc (μg g^{-1} dry wt) and respective confidence limits (CL) in barnacles and mussels from Hong Kong waters, ranked in approximate order of decreasing contamination of samples. Letters in ANCOVA and ANOVA columns denote presence or absence of significant differences between samples

Location (code)	*Capitulum mitella*			*Tetraclita squamosa*			*Balanus amphitrite amphitrite*			*Perna viridis*		
	(Zn)	CL	ANCOVA	(Zn)	CL	ANCOVA	(Zn)	CL	ANCOVA	(Zn)	CL	ANOVA
Hang Hau (12)							11990	14070 10220	A	111	147 75	A
Rennies Mill (11)							11820	14640 9547	B	109	153 65	A
Kowloon Pier (6)				7868	9160 6759	A				108	177 39	A
Hung Hom (7)	19890	32120 12320	A	6963	11370 4266	B				118	168 68	A
Causeway Bay (8)	9305	14720 5879	B	3123	5020 2129	B				150	286 14	A
Stonecutters (17)	6374	10640 3819	B									
Queens Pier (5)	4170	7954 2186	C	4086	6261 2666	B				141	208 74	A
Reef Island (2)	4471	7586 2635	C	4207	6677 2651	B				114	161 67	A
Chai Wan Kok (3)							9353	11800 7411	C	153	247 59	A
Kennedy Town (4)										146	288 4	A
North Point (9)				2534	3083 2084	C	7870	10210 6070	C	96	154 38	B
Kwun Tong (10)							7276	10050 5269	C	115	151 79	A
Tung Chung (1)				2245	3555 1414	C	6491	41600 102	D	86	103 70	B
Wu Kwai Sha (15)							4671	5201 4195	D	65	85 46	C
Tai Po Kau (14)							4381	5620 3415	E	61	80 42	C
Sha Tin (13)							3214	3578 2887	F	66	94 38	C
Lai Chi Chong (16)							2726	7688 967	F	53	67 39	D
Cape D'Aguilar (18)	2852	3944 2062	D									

proposed by Phillips (1985) on the basis of comparisons between zinc contamination profiles for *P. viridis* and other biomonitors in the Victoria Harbour area. Chan (1987) has recently confirmed the ability of *P. viridis* to partially regulate zinc, by the use of laboratory dosing techniques. Other bivalve species known to possess this ability include the mytilid *Septifer virgatus* (Phillips & Yim 1981) and the hairy mussel *Trichomya hirsuta* (Klumpp & Burdon-Jones 1982). *Perna canaliculus* also partially regulates zinc (V. Anderlini, pers. comm. to DJHP). Such regulatory abilities in bivalves do not appear to be as advanced as those in decapod crustaceans (Bryan 1968, 1976, White & Rainbow 1982, 1984, Rainbow 1985, Bryan et al. 1986), but would nevertheless be an interesting area for further study.

The agreement between contamination profiles for elements other than cadmium in the barnacles and mussel studied here implies that the relative bioavailabilities of these metals at each site are similar with respect to all 4 biomonitoring species. However, profiles for cadmium differed substantially between the 3 barnacle species and the mussel, indicating the existence of subtle differences in bioavailability of this element from site to site, to species of divergent feeding habits in Hong Kong waters. The fact that cadmium shows no strong contamination gradient in the Hong Kong coastal environment (Phillips 1979a, 1985) is probably significant, in that such subtle site-to-site variations are more likely where severe contamination does not occur. For elements other than cadmium, the present data also agree well with previous studies of

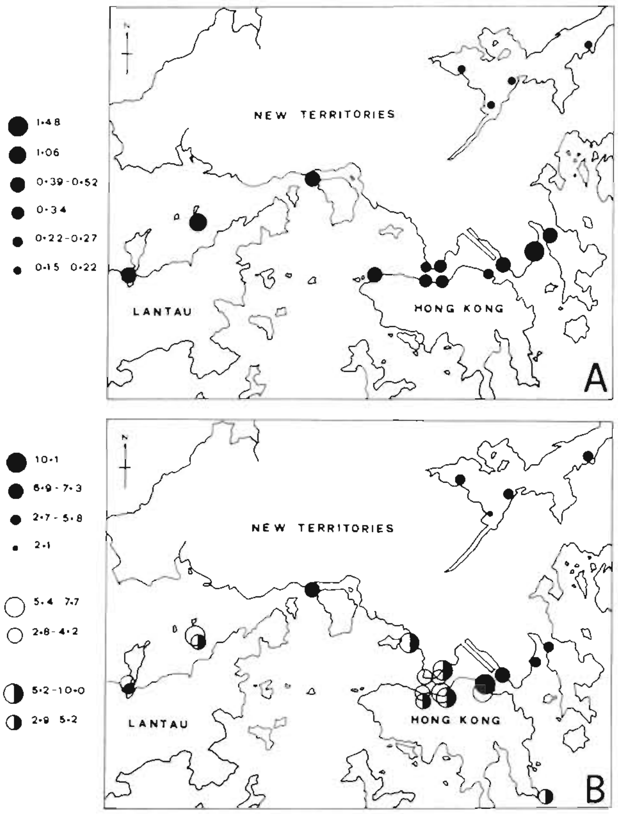

Fig. 2. Concentrations of cadmium ($\mu g\ g^{-1}$ dry wt) in barnacles and mussels from 18 sites in Hong Kong coastal waters. Data for barnacles refer to estimated concentrations for samples of standardized body weight, predicted by ANCOVA treatment; see text for details. Data for mussels shown as mean concentrations of samples, as analyzed. Sizes of circles denote significant differences between sites. (A) Cadmium in *Perna viridis*. (B) Cadmium in *Balanus amphritrite amphitrite* (filled circles), *Tetraclita squamosa* (open circles), and *Capitulum mitella* (half-filled circles)

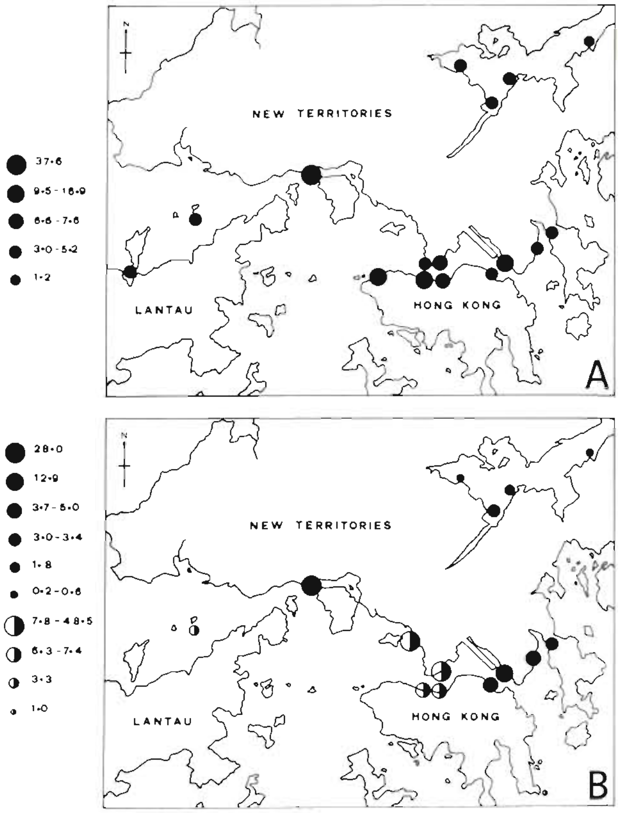

Fig. 3. Concentrations of chromium ($\mu g\ g^{-1}$ dry wt) in barnacles and mussels from 18 sites in Hong Kong coastal waters. Details as in legend to Fig. 2. (A) Chromium in *Perna viridis*. (B) Chromium in *Balanus amphitrite amphitrite* (filled circles) and *Capitulum mitella* (half-filled circles)

oysters, mussels (*Septifer virgatus* and *P. viridis*) and sediments (Phillips 1979a, 1985, Phillips & Yim 1981) in this area of study.

The varying ranges in concentration of the 5 elements studied in barnacles and mussels are also of interest, as they reflect differences in the physiological handling of the metals by each species. The partial regulation of zinc by *Perna viridis* is an extreme case, although the overall contamination profile produced by studies of zinc in mussels nevertheless matched the profiles shown by barnacles, which exhibited very wide ranges in concentration of this element (Table 6). Data for zinc in these barnacles are reminiscent of results for oysters *(Saccostrea glomerata)* from these waters (Phillips 1979a); oysters, like barnacles, accumulate zinc to very high absolute concentrations.

The comparison of species with respect to copper and lead accumulation is also instructive. *Perna viridis* is unusual among mytilids, in that it accumulates very large amounts of both of these elements in contaminated situations. Nevertheless, the 23-fold range between lowest and highest mean concentrations of copper in *P. viridis* from the present study is considerably smaller than the 59-fold range noted for weight-standardized copper concentrations in *Balanus amphitrite amphitrite* (Table 4). By comparison, the ranges between lowest and highest concentrations for lead in these 2 species (Table 5) are very similar, as are the absolute lead concentrations present. Such similarities and differences no doubt relate to the specific methods by which biomonitors sequester trace metals, presumably rendering them non-toxic in the process. Species that are poor regulators of accumulated trace metals are undoubtedly the most effective biomonitors, as intersite differences in concentrations of elements are greater and may overcome more easily the inherent variability among populations at any one site, permitting a more exact ranking of locations with respect to contamination.

Finally, it is worth noting here that insufficient data are available on tropical and subtropical areas of the world in terms of aquatic contamination. This situation

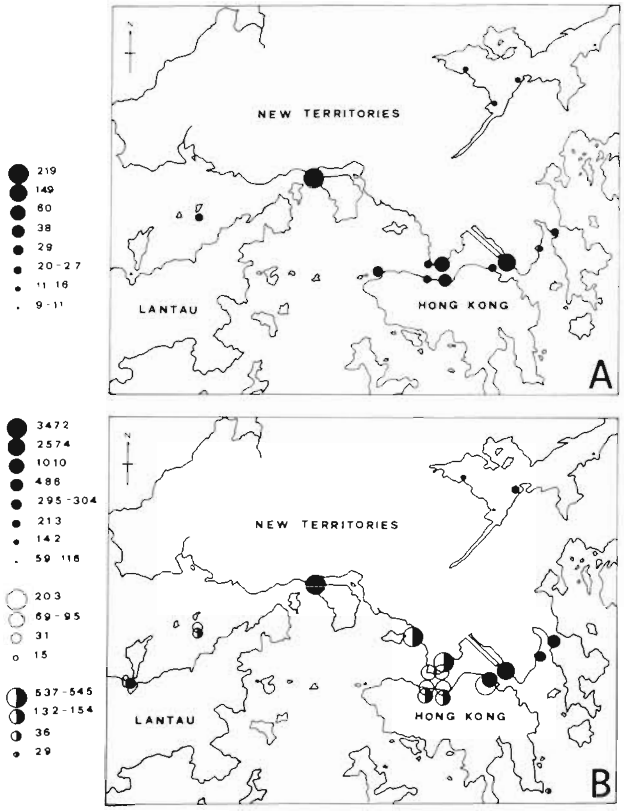

Fig. 4. Concentrations of copper (μg g^{-1} dry wt) in barnacles and mussels from 18 sites in Hong Kong coastal waters. Details as in legend to Fig. 2. (A) Copper in *Perna viridis*. (B) Copper in *Balanus amphitrite amphitrite* (filled circles), *Tetraclita squamosa* (open circles), and *Capitulum mitella* (half-filled circles)

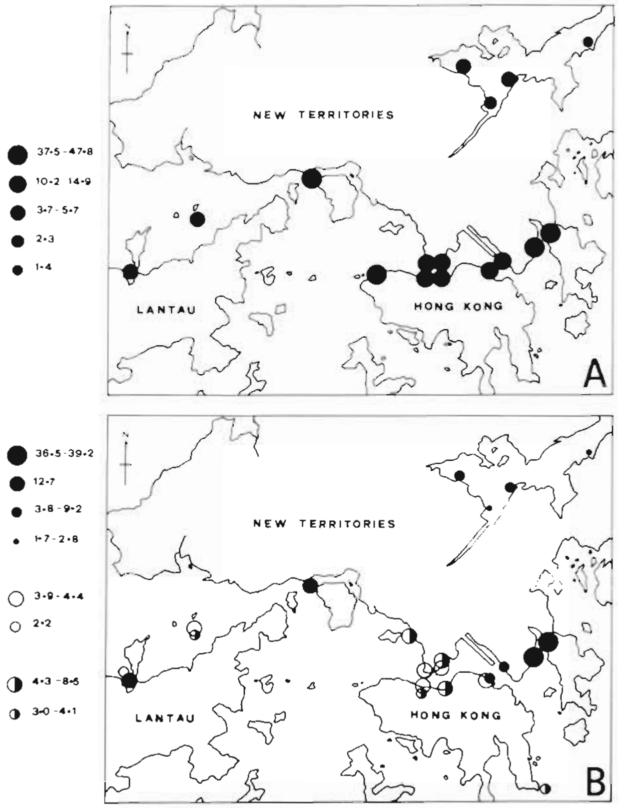

Fig. 5. Concentrations of lead (μg g^{-1} dry wt) in barnacles and mussels from 18 sites in Hong Kong coastal waters. Details as in legend to Fig. 2. (A) Lead in *Perna viridis*. (B) Lead in *Balanus amphitrite amphitrite* (filled circles), *Tetraclita squamosa* (open circles), and *Capitulum mitella* (half-filled circles)

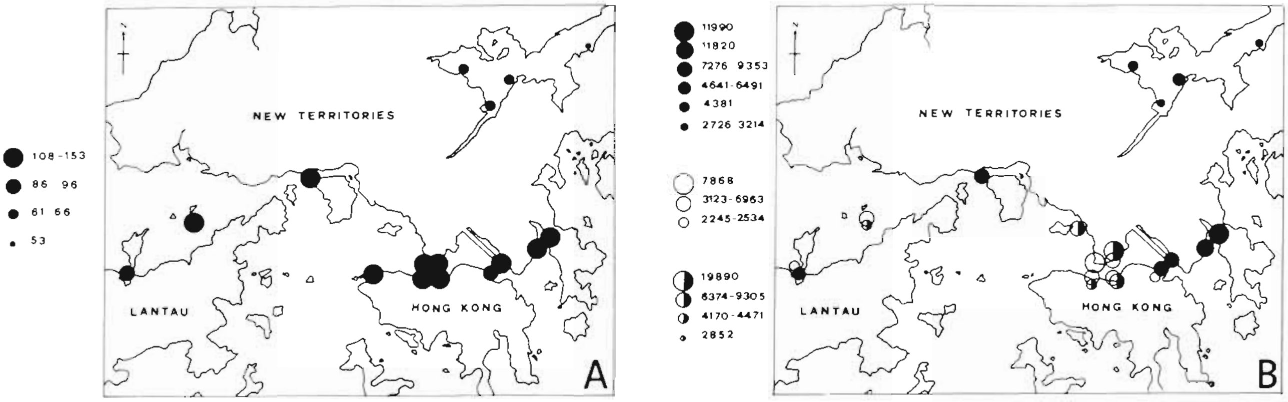

Fig. 6. Concentrations of zinc (μg g^{-1} dry wt) in barnacles and mussels from 18 sites in Hong Kong coastal waters. Details as in legend to Fig. 2. (A) Zinc in *Perna viridis*. (B) Zinc in *Balanus amphitrite amphitrite* (filled circles), *Tetraclita squamosa* (open circles), and *Capitulum mitella* (half-filled circles)

continues despite the rapid urbanization and industrialization of many tropical nations. The use of the cosmopolitan biomonitoring species employed in the present study is recommended in such areas, as a means of both characterizing existing pollution levels and determining future changes in such levels.

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